**Translation**

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Literature References taken into consideration regarding patentability:

DE 40 30 002 A1
US 4, 871, 256
DE-Z: A. Stamm: *Investigations regarding the measuring accuracy of TMS-1 Topographic Modeling Systems*; published in "Kontaktlinse," 1-2/94, pp 26-33

Opposition may be lodged within 3 months following publication of the grant.

## Title: Apparatus and method for determining a plurality of parameters of a curved surface, in particular, a corneal surface

## Abstract:

The present invention relates to an apparatus for determining a plurality of parameters of a curved examined surface, in particular, a corneal surface (1) of the eye. Characteristic of the novel apparatus is a reference target (4b) having a plurality of concentric rings (5), each consisting of a plurality of sequentially adjacent rastered areas (13a, 13b), in which case adjacent rastered areas are different from each other, in peripheral direction as well as in radial direction, regarding their permeability to light. Further, the invention relates to a method for determining a plurality of parameters of a curved examined surface, in particular, a corneal surface (1) of the eye, said method comprising the following steps: contactless measurement of the surface to be examined; generation of a data set which represents the examined surface (1) in a three-dimensional manner; comparison of the data set with a variable model surface and determination of a preferred model surface; determination of the parameters of the preferred model surface as the parameters representing the examined surface.

**Specification:**

The present invention relates to an apparatus for determining a plurality of parameters of a substantially spherical, spheric cylindrical or aspheric cylindrical examined surface. In particular, the apparatus is suitable for the determination of parameters with respect to the examination of a corneal surface of the eye, in which case one important field of use of the apparatus is the determination of parameters of the corneal surface of the human eye.

Furthermore, the invention relates to a method for determining the parameters of a spherical, spheric cylindrical or aspheric cylindrical examined surface, in particular, a corneal surface.

The inventive apparatus and the aforementioned method can be used, in general, for determining the parameters of curved surfaces based on a contactless measurement of the surface to be examined. One important field of use of such apparatus and methods is the measurement and the determination of parameters on the cornea of the human eye. The following description relates mainly to this field of use; however, the protective scope of the present invention is not intended to be restricted to this field alone, but is intended to encompass also the determination of parameters of other examined curved surfaces.

In medicine and optometry, there is a need to be able to measure and model the corneal surface of the human eye as precisely as possible. A knowledge of radii of curvature at various points of the cornea, for example, across flat areas and other irregularities, is required in order to prepare refractive surgical procedures and to produce optimally adapted visual aids (contact lenses or spectacles).

With the aid of conventional ophthalmometric measurements and the measuring method using saggital radii, it is possible to determine central radii of the cornea

and radii at additionally selected measuring points. As opposed to this, the videokeratoscopic method is used to potentially determine the actual gradient of the corneal surface, even between individual measuring points, and thus produce a topographic model of the examined surface.

A known videokeratoscopic apparatus is the TMS-1 topography-measuring system of Tomey AG. Specific features of this apparatus are contained in the company's catalogue having the title "Hornhaut-Topographie, Kornea-Daten mit Präzision – Das TMS-1 (Corneal Topography, Corneal Data with Accuracy – The TMS-1)". Options and limitations of the TMS-1 are described by A. Stamm in the article "Untersuchungen zur Messgenauigkeit der Topographie des Modeling Systems TMS-1 (Investigations regarding the measuring accuracy of Topographic Modeling Systems TMS-1)", published in "Kontaktlinse," Vol. 1-2/94, pp 26 ff. With the use of the TMS-1 and other apparatus designed for determining corneal topography, concentric rings are imaged on the cornea to be measured. The images of these rings reflected by the cornea are recorded, for example, with a CCD camera. Then, the captured images are input into a data-processing system which can be used to compute the topography of the examined surface, thus allowing the determination of the desired parameters.

German Offenlegungsschrift DE 40 30 002 discloses a method and an apparatus for measuring and representing irregularities of the cornea. In order to perform measurements, concentric rings of a reference target are projected on the cornea, whereby the resultant image is reflected and recorded. This is used to obtain data for generating the topography.

US Patent 4 871 256 discloses means for the projection of light patterns. In particular, this document discloses a rotating projection target, which uses stroboscopic light that is projected bit by bit onto a surface to be examined. The projection target, however, does not comprise complete concentric rings with a

plurality of image points having a defined position, thus preventing the application of certain data-acquisition processes.

Considering every known videokeratoscope and the methods used for measuring the corneal surface, it will be assumed, for reasons of simplification, that irregular deviations on the corneal surface occur on a point to be measured only in one direction of curvature of the cornea, namely in the direction of the meridians. Considering an irregular corneal surface, as is frequently the case in real life, this leads to falsified results. In addition, in the known measuring methods, eccentricity, prismatic effect, point of symmetry (apex of the ellipsoid) and the refractive center of the examined cornea are not taken into account.

One object of the present invention is to overcome the disadvantages of prior art and to provide an apparatus which permits a more exact measurement of spherical, spheric cylindrical or aspheric cylindrical surfaces that are to be examined.

Another object of the present invention is to provide a method that yields sound and convincing measured data of a curved examined surface and that these data are processed in such a manner that the most realistic and faithful description and/or modeling of the examined surface can be achieved. In particular, improved data of the actual topography of the cornea of the human eye are to be acquired.

On one hand, this object is achieved by the apparatus disclosed in Claim 1 and, on the other hand, by the method disclosed in Claim 7.

The inventive apparatus offers the advantage that the image of the projection target (hereinafter also described as the reference target) projected on the examined surface comprises a plurality of defined image points, each having a

clearly definable position. In contrast with prior-art apparatus, the recorded image points can be unambiguously assigned to the projection target not only in view of the respective radius of the concentric ring. In addition, an exact determination of the angle is possible, because a plurality of defined target points along the concentric rings is provided.

In an advantageous embodiment of the inventive apparatus, the concentric rings are divided into a first group of inner rings and a second group of outer rings. In so doing, the rastered areas within the first group or the second group are formed by regular trapezoidal areas. Within the first and second groups respectively, these trapezoidal areas are arranged in radial direction in such a manner that the sides of the trapezoidal areas are formed by radius lines, so that each ring of one and the same group has the same number of rastered areas. The group of inner rings comprises a smaller number of rastered areas than the group of outer rings; and, between the groups, a transition ring is provided which has rastered areas configured in such a manner that they, in radial direction, are adjacent rastered areas of neighboring rings exhibiting different permeability to light. This design offers the advantage, considering the inner rings as well as the outer rings, that the size and number of rastered areas can be adapted to the circumference of the rings, without resulting in too coarse a resolution of the outer rings and without having the rastered areas of the inner rings so close to each other that they can no longer be optically resolved. Even though the number of rastered areas between the groups of inner and outer rings varies, interposed transition rings ensure that unambiguously definable boundary edges between the rastered areas exist even in these locations, this being necessary for a correct, optionally automatic, analysis of the recorded image. In a modified embodiment, the number of rastered areas of a ring of a radially outer group is twice as high as the number of rastered areas of a ring of a radially inner adjacent group. A preferred embodiment is further characterized in that the concentric rings are divided into four groups so that the rings of the radially outermost group comprise 256 or 128

rastered areas. This value is advantageous for a corneal topography-measuring apparatus, in which the outer ring has a diameter within the range of 7 to 12 mm.

A particularly effective embodiment of the inventive apparatus is characterized in that light-permeable and light-impermeable rastered areas are used. This provides a black-and-white transition between rastered areas, thus simplifying image recording and analysis.

In a modified embodiment, the rastered areas are dyed different colors, so that good permeability exists for only one narrow light-wave spectrum per rastered area. For example, the rastered areas may be alternately dyed red, green and blue, or they may be opaque. If these rastered areas are dyed such that their colors repeat regularly, coding becomes possible and thus a rapid detection of the current position on the referenced target.

The inventive method described in Claim 7 offers the advantage that, based on the exact determination of the position of the image points on the examined surface, a plurality of data may be acquired, which can be used to represent the examined surface with high accuracy. Furthermore, the comparison of the determined examined surface with a variable model surface makes it possible that the parameters describing the examined surface can be determined with minimal effort for a plurality of examined surfaces, even when the examined surface has irregular components.

It is particularly advantageous when the inventive method is carried out with an inventive apparatus. The plurality of measured data determined with this apparatus permits high accuracy regarding the representation of the examined surface, so that extensive modeling of the real, examined corneal surface is achieved in this manner. Considering an advantageous embodiment, when comparing the data set with the variable model surface, for each image point the

corresponding point of the model surface is selected, whereby the position of said latter point coincides – with respect to the first dimension (x-direction) and the second dimension (y-direction) – with the position of the image point; then, the position differences with respect of the third dimension (z-direction) between the image point and the selected point on the model surface is determined; and then, based on the position differences of all considered points, the volume included between the model surface and the examined surface is determined. Then, the selected preferred model surface is that model surface for which the included volume is minimal.

Furthermore, it is advantageous if, at the time the data set is generated for each individual image point, its associate target point is identified and, considering said point, the exact position of the image point on the examined surface is computed. This is necessary because the image of the reference target projected onto the cornea is irregularly reflected at certain points of the cornea, so that the recorded image does not exactly correspond to the projected image but displays irregular changes. The computation of the exact position of the image point on the examined surface is achieved by using the parameters of the apparatus design and by the used measuring system, whereby the offset between the apex of the examined surface and the position of the image point in z-direction, the height between the apex of the examined surface and position of the image point in y-direction, and the radius of curvature of the examined surface at the image point are computed based on the measured data. In this manner, irregular reflections on the cornea can be defined, so that even irregularly reflected image points can be analyzed and their exact position on the corneal surface can be computed.

In a preferred embodiment of the inventive method, the residual deviation between the examined surface and the determined preferred model surface is determined as the residual volume between these two surfaces. In a modified embodiment, this residual deviation can be determined by adding the distances

between the two surfaces at certain points, provided these points are selected in such a manner that they always refer to an unchanging surface component.

In one embodiment, the method is modified in such a manner that the expected visual acuity deterioration can be determined based on the reduced imaging quality of a corneal surface. As a result of this, it is possible to use the irregular components that have been determined on the corneal surface to directly determine the expected deterioration of visual acuity.

Additional advantages, details and modifications can be learned from the following description of preferred embodiments with reference to drawings. They show in

Fig. 1 a schematic diagram of the design and optical path of an apparatus for the examination of the corneal surface, as in prior art;

Fig. 2 a simplified illustration of a reference target, in which case a prior art embodiment of the reference target is shown and an inventive embodiment of the reference target is shown;

Fig. 3 in a simplified three-dimensional depiction, the optical path of the inventive apparatus.

Fig. 1 shows a simplified representation of the optical path of a prior-art apparatus for measuring the corneal topography. This apparatus is to be used for mapping corneal surface 1 having an apex 2, through which extends optical axis 3 in this drawing. In addition, this apparatus comprises a reference target 4a, preferably a disk having a plurality of concentrically arranged rings 5. Inasmuch as concentric rings 5 display different permeabilities to light, adjacent rings have, along their boundary edges, a defined peripheral line of target points 6. By

illuminating reference target 4a, an image of a target point 6 is projected on the optical path onto cornea 1 as in Fig. 1, so that an image of a projection point 7 is created there. A projection beam 8 creating an image of target point 6 is reflected partially at projection point 7 and proceeds as reflected beam 9 to an image plane 10 of an image-recording device that is not illustrated in detail. Consequently, an image point 11, which can be used for data acquisition, is created on image plane 10. Reflected beam 9 crosses optical axis 3 at the location of a camera aperture 12 of the image-recording unit.

Furthermore, Fig. 1 shows the radius $p$ of concentric ring 5; distance $q$ between camera aperture 12 and apex 2 of the cornea; distance $t$ between apex 2 and the plane of concentric ring 5, the so-called rising height $z$, i.e., the distance between apex 2 and a plane parallel to the plane of concentric ring 5, through projection point 7; radius of curvature $r$ of cornea 1; and, the so-called zone height $y$, i.e., the perpendicular distance between projection point 7 and optical axis 3.

Videokeratoscopy, which is performed with a prior art apparatus, assumes, for ease of understanding, that projection beam 8 on image point 7 is reflected only in a [sic.] perpendicular to image plane 10 and to the plane of concentric ring 5 (in Fig. 1, this corresponds to the drawing plane). Reflections in other directions are ignored in the case of these apparatus and methods. Also, it is not possible to determine at what target point 6 along the peripheral line of a concentric ring 5 this projection point 7 has its origin.

Image point 7 (projection point) on corneal surface 1 on said point's characteristic coordinates $z$, $y$ and $r$, can be computed by applying rules of geometry as expressed by the following equations:

$$\frac{y}{\sin\alpha} - r = 0 \tag{1}$$

$$r = \frac{y^2 + z^2}{2 \bullet z} \tag{2}$$

$$y = \tan\beta \bullet (q + z) \tag{3}$$

$$\gamma = \arctan\frac{p - y}{t + z} \tag{4}$$

$$\alpha = \frac{\gamma - \beta}{2} \tag{5}$$

If equations (2), (3), (4) and (5) are inserted in equation (1), the following results:

$$\frac{\tan\beta \bullet (q + z)}{\sin\dfrac{\arctan\dfrac{p - (\tan\beta \bullet (q + z))}{t + z} - \beta}{2}} - \frac{(\tan\beta \bullet (q + z))^2 + z^2}{2 \bullet z} = 0 \tag{6}$$

Using equation (6), rising height *z* is determined first. By inserting *z* in equation (3), and by subsequently inserting *z* and *y* in equation (2), radius *r* can then be computed.

Fig. 2 shows a schematic diagram of a reference target. For better understanding, the reference target is shown divided in two halves, whereby the lower half of the illustrated disk shows a reference target 4a known from prior art, while the upper half shows reference target 4b of the present invention. In accordance with prior art, such reference targets are configured as a disk with concentric rings, for example, whereby adjacent rings are different from each other regarding their permeability to light. In the least complex case, light-

impermeable concentric rings 5a and light-permeable concentric rings 5b are provided. In modified embodiments, several successive concentric rings are arranged in conical sequence, so that the reference target exhibits a spatial expansion but appears as shown in the projected image in the lower half of Fig. 2. In the inventive apparatus, reference target 4b, for example, has the design as shown in the upper half of Fig. 2.

In order to obtain a more accurate map of the topographic configuration of the cornea by measuring the corneal surface, the deflection of the reflected beam in directions, which are not perpendicular to the recording plane, may not be ignored. To accomplish this, it is necessary that target point 6 is defined not only as to its distance from optical axis 3, but, in addition, a corresponding angle on reference target 4b can be indicated, so that target point 6 can be unambiguously identified. Therefore, the inventive reference target 4b, for example, has light-impermeable rastered areas 13a and light-permeable rastered areas 13b. The rastered areas are arranged in concentric rings 5, whereby light-permeable and light-impermeable rastered areas alternate successively. The rastered areas are arranged offset in adjacent concentric rings, so that, even in radial direction, one light-impermeable rastered area 13a is respectively adjacent one light-permeable rastered area 13b. A light-permeable rastered area 13b is bordered on all sides in peripheral direction of the concentric rings, as well as in radial direction, by light-impermeable rastered areas 13a. Light-permeable rastered areas 13b thus form individual target points 6, the image of which is projected onto cornea 1. In order to be able to unambiguously identify each target point, the reference target has an identifier 14 defining the zero line, starting from which rastered areas can be counted. However, other types of codes may also be used to identify each individual target point.

Fig. 2, upper half of the illustration, shows a special embodiment of the reference target, which is characterized in that the concentric rings, each comprising a

plurality of rastered areas, are divided into several groups. In order to achieve sufficient resolution for measuring purposes, a plurality of rastered areas 13 must be provided in the outermost ring. Considering an outermost-ring radius of approximately 4 mm, for example, 128 rastered areas 13a, 13b are provided along the periphery of this outermost ring. Inasmuch as light-impermeable and light-permeable rastered areas are supposed to also alternate in radial direction at each point of the reference target, 256 rastered areas would have to be provided even in the innermost ring , considering a completely regular design of the concentric rings. This would result in making the rastered areas in the inner rings so small that they could no longer be resolved individually. In the illustrated and preferred embodiment, concentric rings 5 are divided into four groups, in which case, within each group, each concentric ring has the same number of rastered areas. A transition ring 15, having specially configured rastered areas, is provided between each of the individual groups. The rastered areas of the transition ring are configured in such a manner that, in radial direction, again at each location of adjacent concentric rings, a light-permeable rastered area follows a light-impermeable rastered area. In the depicted embodiment, the number of rastered areas decreases by half with respect to the adjacent inner group. In order to achieve the desired effect, the rastered areas in transition ring 15 may have the shape of a triangle or a trapezoid. One example of a configuration of the transition ring is shown in Fig. 2.

In modified embodiments, colored rastered areas may be used, which, again, are arranged in an alternating manner. If the reflected image points are also recorded in color, this feature may be used for coding the individual position on the reference target, so that the affected target point 6 can be identified faster among the plurality of rastered areas. Other configurations of the reference target are conceivable, thus allowing the unambiguous identification of individual target points.

Fig. 3 shows a schematic diagram of the progression of the beam in an inventive apparatus. Since, in accordance with the invention, the optical path must be exactly considered also with regard to the third dimension, this optical path is shown in perspective in Fig. 3 for ease of understanding. Due to an irregularity of corneal surface 1, projection beam 8, when reflected, is deflected in two directions, so that image point 11 appears on image plane 10 at an angle of 270 degrees. With the use of a prior-art apparatus, such an image on image plane 10 would lead to the conclusion that projection point 7 corresponds to a false target point 16, which is located reference target 4 at an angle of 90 degrees. With the use of the inventive reference target 4b, however, it is now possible to identify the actual target point 6. Thus, the actual position of projection point 7 on corneal surface 1 can also be determined.

Projection point 7 can be described in an unambiguous manner regarding its position on corneal surface 1, when rising height *z*, zone height *y* and radius of curvature *r* can be stated. In order to determine these three coordinates in the cylindrical system of coordinates that is used as basis, the angle of incidence *ß* of reflected beam 9 is determined by analyzing the position of image point 11 on image plane 10. Distance *q* between the camera aperture and the apex of the corneal surface can be determined conventionally with the use of an appropriate length-measuring system. Likewise, radius *p* of the concentric ring may be presumed as known, because the dimensions of reference target 4b are known and, for example, may be stored in an appropriate data processing unit. Likewise, distance *t* between ring plane and apex can be determined in a conventional manner. In order to determine the exact coordinates of projection point 7, however, the subsequent computation must not start with radius *p* of the concentric ring, but the actual position of target point 6 must be taken into account.

The coordinates *z*, *y* and *r* are determined with the use of the above-mentioned equations (1) through (6). However, in so doing, a corrected radius *m* is used instead of radius p of the concentric ring. The corrected radius *m* is determined as expressed by the equation

$$m = p \bullet \cos \delta \quad (7)$$

wherein δ represents the angle between false target point 16 and actual target point 6. After the coordinates have been determined in the described manner for a plurality of projection points 7, a data set has been created which describes the topographic progression of the corneal surface.

Furthermore, the invention discloses a method which can be used to determine a plurality of parameters which characterize this mapped corneal surface. For example, it is desirable that the following parameters be determined for fitting contact lenses:

- apical radius of the cornea,
- cylindrical effect and the cylinder axis,
- eccentricity,
- decentering and its prismatic effect,
- refractive center,
- apex of the ellipsoid referred to as the point of symmetry.

Inasmuch as the actual corneal surface, as a rule, is not a simple, spherical, spheric cylindrical or aspheric cylindrical surface but frequently displays irregularities, a deviation of the actual corneal surface will remain with respect to a model surface that can be expressed in terms of simple mathematical functions. This deviation is referred to as an irregular component.

In accordance with the inventive method, an appropriate data processing program is preferably used to compare the actual corneal surface described by the determined data set with a model surface having known parameters. The model surface is mathematically altered in order to determine one preferred model surface from among numerous possible model surfaces. This preferred model surface is characterized in that its form deviates the least from the actual examined surface (corneal surface). The deviation between the preferred model surface and the examined surface can be determined, for example by determining the volume included between these two surfaces. If the included volume equals zero, the examined surface and the model surface coincide. Thus, the preferred model surface is that surface which displays a minimal included volume. This included volume can be determined mathematically in a manner known per se, in that the individual image points of the data set describing the examined surface is compared with associate points of the model surface.

After the preferred model surface has been determined, the known parameters of the model surface can be used to describe the examined surface. The remaining deviation, referred to as residual volume, between the examined surface and the preferred model surface is a measure of the irregular components of the examined surface.

Furthermore, the determined irregular component can be used to determine an expected deterioration of visual acuity based on the reduced imaging quality of the examined corneal surface. To accomplish this, during a first step, a spherical reference surface is computed and is represented with the aid of a data set. The spherical reference surface may represent, for example, a corneal surface having an index of refraction of 43.0 diopters (dpt). In addition, a cylindrical reference surface is computed and is represented by a corresponding data set. The cylindrical reference surface has a cylinder height $D$ greater than zero dpt. The cylinder height $D$ is selected such that the spherical reference surface is the

spherical equivalent of the cylindrical reference surface. In the said example, the cylindrical reference surface can accept refractive indices of 43.5/43.5 dpt, 42.0/44.0 dpt or 41.5/44.5 dpt. Hence, the cylindrical effect of the cylindrical reference surface is expressed in refractive indices of 1, 2 or 3 dpt. The spherical and cylindrical reference surfaces are positioned in a coordinate system in such a manner that they have one common apex. Then, the volume included between the spherical and the cylindrical reference surfaces may be determined. By appropriate computations, the reference surfaces are matched in such a manner that the volume included between them is substantially equal to the residual volume, which is included between the examined surface and the preferred model surface. If this condition is met, cylinder height D of the reference surface can be used to determine visual acuity deterioration $V_S$. Visual acuity deterioration $V_S$ is determined as expressed by the following formula:

$$V_S\,[\%] = 100 - \frac{100}{2^{D\,[dpt]}} \qquad (8)$$

It is evident that the use of the inventive apparatus permits a more accurate measurement of an examined surface, in particular, a corneal surface, than is possible with conventional apparatus. This more accurate mapping is the basis for a realistic topographic description of the examined surface. With the use of the determined data set and the inventive method, a preferred model surface, which – regarding its topography – largely corresponds to the examined surface, can be determined. With the use of this preferred model surface, parameters, which characterize the preferred model surface, as well as the examined surface, can be determined in a simple manner. These parameters can be used for determining the optical properties of a corneal surface, for example. In addition, the inventive method can be used to determine the irregular component of an examined surface and to use it in a corneal examination for determining the expected deterioration of visual acuity.

The suggested apparatus and the described method have been explained mainly with reference to the determination of corneal surface parameters. However, the protective scope of the present invention also covers the use of the apparatus in other fields and the use of the method, in general, for the determination of parameters of spherical, spheric cylindrical or aspheric cylindrical examined surfaces.

## Patent Claims:

1. Apparatus for determining a plurality of parameters of a substantially spherical, spheric cylindrical or aspheric cylindrical examined surface, in particular, a corneal surface (1) of the eye, comprising:
   - a projection target, which has a plurality of clearly divided areas (5) exhibiting different permeabilities to light and the image of which is projected onto the examined surface (1);
   - an image-recording unit, which records an image reflected by the examined surface (1);
   - a data processing unit which processes the recorded image;

   **characterized in that** the projection target (4b) has a plurality of concentric rings (5), each consisting of a plurality of sequential rastered areas (13a, 13b), in which case adjacent rastered areas differ from each other regarding their permeability to light in peripheral direction, as well as in radial direction.

2. Apparatus in accordance with Claim 1, characterized in that the concentric rings (5) are divided into at least a first group of inner rings and a second group of outer rings, whereby the rastered areas (13a, 13b) inside the first group and the second group respectively, are created by regular trapezoidal areas, in which case columns of rastered areas are arranged in radial direction between radial lines, so that each ring of one and the same group has the same number of rastered areas, in which case the group of inner rings has a smaller number of rastered areas than the group of outer rings, and in which case, between the groups, a transition ring (15) is provided, said ring having rastered areas which are configured in such a manner that they are adjacent, in radial direction, rastered areas of adjacent rings that display a different permeability to light.

3. Apparatus in accordance with Claim 2, characterized in that the number of rastered areas (13a, 13b) of a ring of a group located radially outward is twice the number of the rastered areas of a ring of an adjacent group located radially inward.

4. Apparatus in accordance with Claim 3, characterized in that the concentric rings (5) are divided into four groups, and that the radially outermost group has 256 or 128 rastered areas (13a, 13b).

5. Apparatus in accordance with Claims 1 through 4, characterized in that light-permeable (13b) and light-impermeable (13a) rastered areas exist.

6. Apparatus in accordance with one of the Claims 1 through 5, characterized in that the rastered areas are dyed in different colors, so that good permeability to light exists for only one narrow light-wave spectrum per rastered area.

7. Method for determining a plurality of parameters of a substantially spherical, spheric cylindrical or aspheric cylindrical examined surface, in particular a corneal surface (1) of the eye, comprising the following steps:
   - contactless mapping of the examined surface, whereby
     - an image of a projection target (4b) with a plurality of target points (6) having an unambiguously defined position is projected onto the examined surface;
     - an image reflected by the examined surface (1) is recorded, said image comprising a plurality of image points (11) assigned to the target points (6);
   - generation of a data set of image points (11), said set representing the examined surface (1) in a three-dimensional manner;

- comparison of this data set with the data set of a model surface, which can be varied by previously entered parameters, and determination of a preferred model surface, which, in view of previously determined criteria, deviates the least from the examined surface represented by its data set;
- determination of the parameters representing the examined surface as the parameters of the preferred model surface, and determination of the residual deviation between the preferred model surface and the examined surface.

8. Method in accordance with Claim 7, characterized in that the projection target (4b) consists of a plurality of adjacent clearly divided areas (13a, 13b) which exhibit different permeabilities to light and which are arranged in an alternating manner.

9. Method in accordance with Claim 7 or 8, characterized in that an apparatus as in one of the Claims 1 through 6 is used for carrying out said method.

10. Method in accordance with one of the Claims 7 through 9, characterized in that the step of comparing the data set with the variable model surface comprises the following partial steps:
    - for each image point (11), the associated point of the model surface is selected, whereby said latter point's position corresponds to the image point in view of the first dimension (x-direction) and the second dimension (y-direction);
    - the position difference with respect to the third dimension (z-direction) between the image point and the selected point of the model surface is determined;

- the position differences of all the considered points are used to determine the volume included between the model surface and the examined surface;
- the preferred model surface is identified as that model surface which displays a minimal included volume.

11. Method in accordance with one of the Claims 7 through 10, characterized in that the step of generating the data set for each image point (11) comprises the following partial steps:
    - identification of the associate target point (6);
    - computation of the exact position of the image point (11) on the examined surface (1), whereby the following are determined:
        - the rising height (z) between the apex of the examined surface and the position of the image point in z-direction;
        - the zone height (y) between the apex of the examined surface and the position of the image point in y-direction; and,
        - the radius of curvature (r) of the examined surface on the image point.

12. Method in accordance with Claim 11, characterized in that the associate target point (6) is identified in that, starting from a defined zero point (14), the rastered areas (13a, 13b) located between the target point and the zero point are counted.

13. Method in accordance with one of the Claims 7 and 12, respectively, characterized in that the residual deviation is determined as the residual volume between the preferred model surface and the examined surface.

14. Method in accordance with Claim 13 for determining the deterioration of visual acuity based on the reduced imaging quality of a corneal surface (1) of the eye, comprising the following steps:

- mathematical representation of a spherical reference surface;
- mathematical representation of a cylindrical reference surface with a cylinder height (D) greater than 0 diopters (dpt); whereby
  - the spherical reference surface forms the spherical equivalent of the cylindrical reference surface;
  - the spherical and the cylindrical reference surfaces have a common apex;
  - the volume included between the spherical and the cylindrical reference surfaces is substantially equal to the residual volume;
- determination of the visual acuity deterioration ($V_S$), starting with the cylinder height (D), as expressed by the following formula:

$$V_S\,[\%] = 100 - \frac{100}{2^{D\,[dpt]}}\,.$$

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Regarding this, see 3 pages of drawings.

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# Fig. 1

*-- Prior Art --*

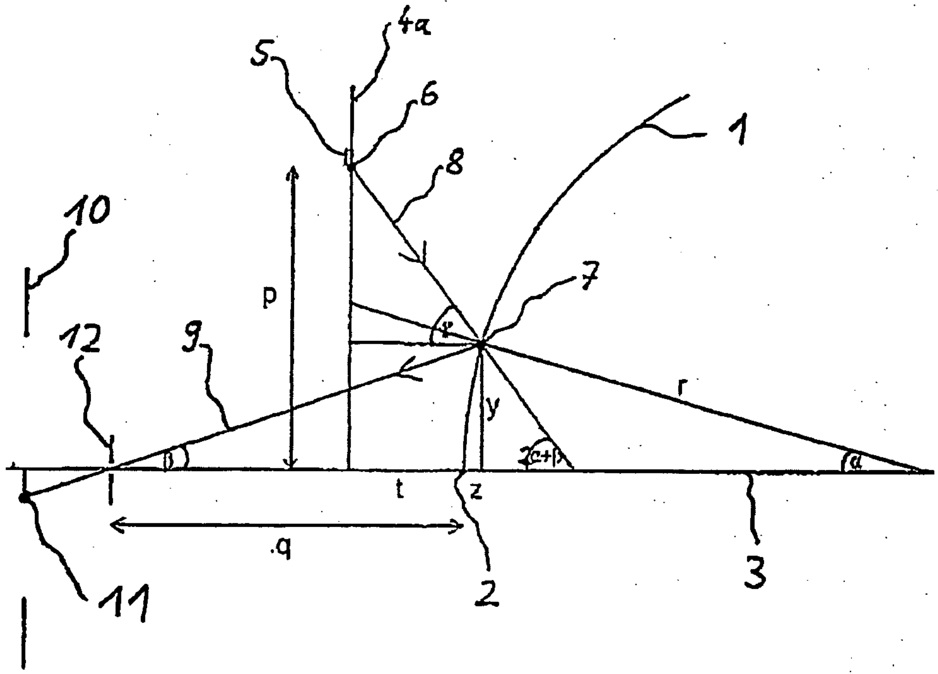

Fig. 2

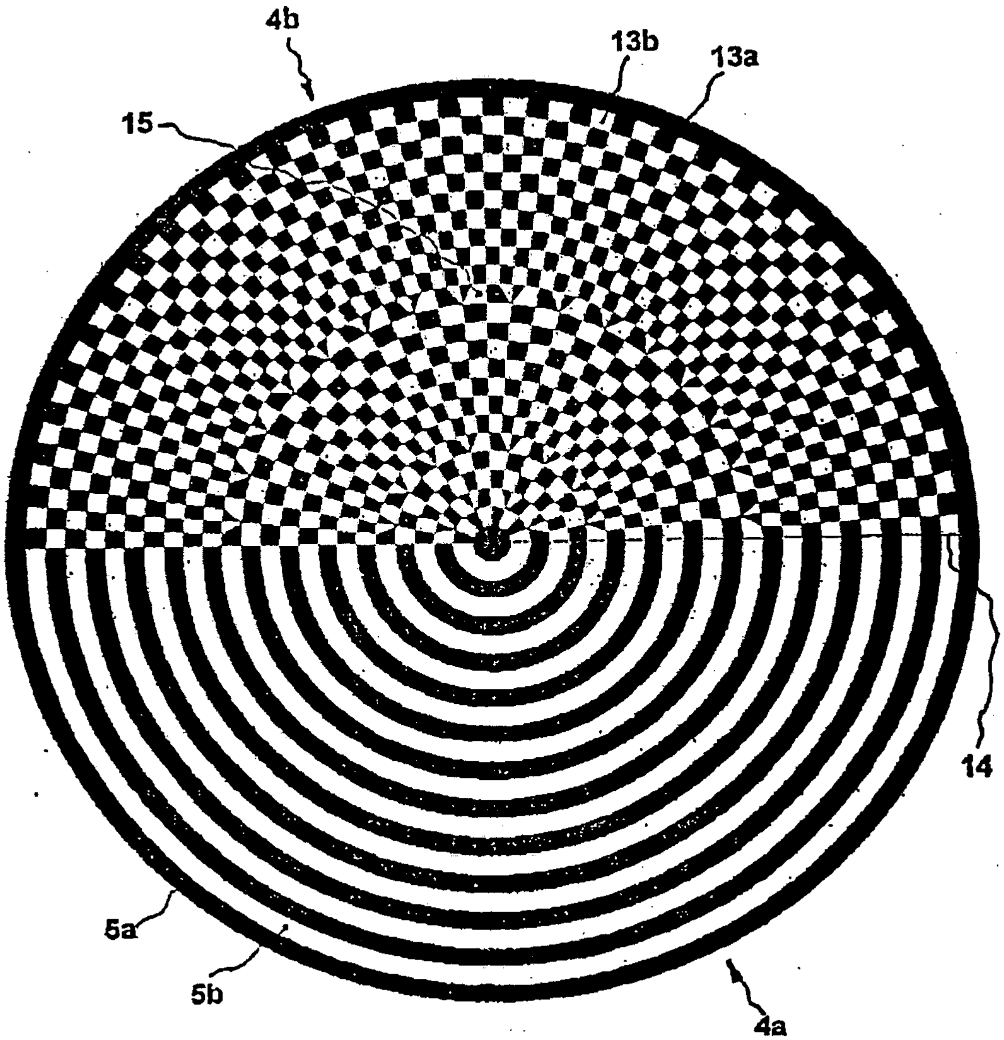

Fig. 3